AuditoryPong – Playing PONG in the Dark

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Abstract. Almost all computer games today are based on a visual presentation on the screen. While the visual realism advanced the main baseline of the interaction remains the same – when you switch off the display the fun is gone. In our research, we aim to provide non-visual access to computer games providing blind and sighted players with fun and pervasive interaction. As an application example we developed AuditoryPong, an interactive game that transfers the game PONG into a physical and acoustic space. The central elements of the game are transformed to moving and movable acoustic objects in a 3D acoustic environment. Based on the current acoustic game state the user moves the game paddle with body interaction or haptic devices and receives immediate acoustic feedback. Players do not need the visual display and sighted and blind people can play PONG together.

1. Introduction

Most of today's available games provide magnificent graphics to simulate fantastic worlds. The quality of the visual output constitutes a crucial factor for the game experience. Sound effects are becoming more realistic as well. However, similar to other non-visual modalities sound often serves mainly as an add-on for better entertainment without having a major impact on the game design and without transporting much primary information to the user.

There are already multiple examples were sound has a major impact not only on experiencing games, but also as a necessary part to play a successful game, e.g. first-person shooter. In previous research we developed, for example, a multimodal presentation for a mobile paper chase game. We used non-speech sound instead of a graphical map to provide information about the location of the next geo-referenced riddle [1]. Unfortunately, not all people are able to participate in the improvement of current game developments. Visually impaired and blind people do not have access to visual-oriented games, reducing their possibilities becoming entertained, having fun, getting socialized, and competing with others.

Apart from games developed for sighted players only, there are games specifically developed for user groups with special needs, e.g. auditory games for the blind. One of the first audio only games was "Sleuth - an audio experience" [2], which uses not only pure auditory cues but also speech output. Further examples of acoustic games are the sonification of the Towers of Hanoi [3] and the non-speech acoustic output for the games Mastermind and Tic-Tac-Toe developed by Targett et al. [4]. Auditory games for the blind are normally based on visual games with a very simple game idea. Their visual artefacts differ often only in their form or colour. This information can be quiet easily transferred into another modality. However, similar to visual oriented games, these games do not make use of the full potential of games in the sense of supporting the inclusion of different user groups. A game specifically developed for a blind user, for example, can typically be played only by the blind user, against a computer opponent or against other blind people in case of a multi-player game. Playing across different user groups with different visual capabilities is not possible.

In this paper, we propose the non-visual game "AuditoryPong" that can be played by sighted and blind users against each other. Based on the early published computer game PONG, we developed a new presentation metaphor and interaction techniques allowing blind people to interact within a virtual sound environment, perceiving game events, and controlling game artefacts, while sighted users still can use their well known input and output devices. The participants of the game can play at the same physical location but also over the Internet. The game design allows a sighted user to play the game without seeing a display but the player can also use a visual game interface. In AuditoryPong we bring the different user groups together as the game has been consistently translated from a visual interaction paradigm into an acoustic interaction paradigm. Through this, the game's idea, its elements, and interaction remain while enabling both user groups to hopefully win the game.

The remainder of this paper is structured as follows: The next section shortly recaps the original computer game PONG to the readers. The paper elaborates on the challenges and requirements of transferring the visual-oriented game into a pervasive acoustic and physical environment. Then we present the non-visual interaction design including the various input devices we developed or adapted for AuditoryPong. We describe the design and implementation as well as our experiences during several public demonstrations. The paper closes with a conclusion and an outline of our future work.

2. The Original PONG Game

One of the most prominent and early example of a visual computer game is PONG. Originally PONG game was invented by Nolan Bushnell and first published already in 1972 by Atari Inc. The game was first designed as an arcade game. Later it became very popular on home consoles like the Tele-Games console shown in Figure 1.

PONG is played on a two dimensional game field, which is divided into two halves. Figure 2 and Figure 3 illustrate the game layout and game elements. The user can choose between to layouts: horizontally – playing from the left to the right as shown in the figures – or vertically – playing from the top to the bottom. After starting the game, a ball represented by a small dot moves over the field from one side to the other.

Figure 1: PONG arcade console (left)
and home console (right) [5].

Each player's goal is to make sure that the ball is not moving across the own baseline. To achieve this goal, the user can move a paddle along the baseline and try to hit the ball. If the player fails, the opponent scores, otherwise the ball collides and bounces back. The two other borders of the game field consist of walls. Each time the ball collides with a wall or paddle, the game plays a "beep" sound. The game is either played alone against the computer or against a human opponent. Both players are playing on the same machine at the same location.

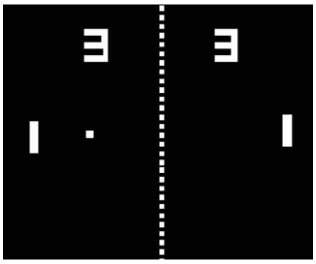

Figure 2: Original PONG game layout

3. Transferring PONG into a Non-Visual Game

In order to transfer PONG into a non-visual game, for example to make the PONG game accessible for blind people, the player needs to be able to perceive any of the visual information in a suitable modality. Furthermore the player must be able to control the main game elements. In this section, the game is analyzed in more detail to identify the information, which are exchanged between user and computer. The game field of PONG is a rectangular two dimensional area bordered by two walls on the sides and two baselines in multiplayer mode or one baseline and another wall in single player mode. The solid walls ensure that the ball rebounds if it hits the wall. Furthermore, the paddle cannot be moved through the walls. Figure 3 shows the basic game elements of PONG.

3.1. Presenting the Ball and its Location

One prerequisite to play the game is to perceive the location of the ball. For the design of AuditoryPong it is important to know when, how often, and how accurate the location of the ball needs to be perceived by the player.

The ball moves continuously within the game field. The primary user task is to manoeuvre the paddle to the position where the ball would hit the baseline. Keeping in mind that it takes some reaction time and time to move the paddle to a certain position on the baseline, we can conclude that the user must predict the ball's position in the near future. The player can achieve this by analyzing the movement of the ball. For this the ball's location must be presented continuously to the player as it is implemented in the original PONG through "moving" the ball's pixels. The accuracy and the time horizon of the prediction depends on many factors: the size of the game field in relation to ball and paddle, the velocity of the ball, and the speed the user is able to manoeuvre the paddle. If these parameters remain constant, we can conclude for the presentation of the ball's location, that the closer the ball approaches the player's baseline, the more accurate the information of the ball's location needs be presented. If the ball is near the opposite baseline, the location presentation can be less accurate.

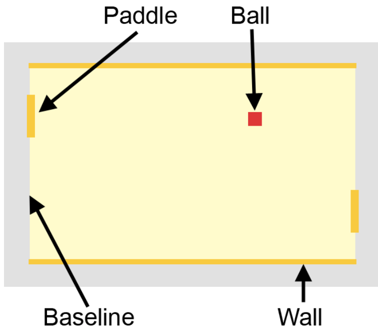

Figure 3: PONG's game elements

PONG consists of several game elements that need to be presented to the user. The user must be able to distinguish these elements and to identify the ball. The exact presentation of the ball strongly depends on the final interaction design. However from the above requirements for the location presentation, we can conclude that the ball is permanently displayed to the user. Therefore a presentation should be used, which does not annoy the user and allows an easy and accurate localization. It should not prevent the identification of other game elements. The representation must reflect the current position of the ball immediately.

3.2. Presenting the Paddle and the Field

Manoeuvring the paddle to the position on the baseline, where the player assumes that the ball will cross it requires some knowledge about the paddle. Primarily the player needs to know the current location of the paddle in relation to the ball or more precisely the location where the ball is assumed to hit the baseline. The player can then decide if and in which direction he or she has moved the paddle. In addition, the user should get an impression of the paddle's size in relation to width or height of the field. Although this relative information should be enough to play the game, it will help the player to perceive the absolute extent of the paddle to get a better idea of how far the paddle has to be moved.

An impression of the field extent helps the player to imagine the maximum distance that is covered by the paddle. The player needs to get a general image of the game layout, i.e. if the game is played horizontally or vertically.

3.3. Presenting Game Events and Moving the Paddle

It is necessary to present all events of the game and actions of the user to increase the fun of the game and to enable the users to enhance their playing abilities. Feedback on certain actions and game events – other than the movement of the ball – should be given to the user. The prominent pong-sound in the original game is one of such feedbacks. It occurs when the ball collides with a wall or paddle and informs the user about a change of the ball's movement direction. Another event is the collision of the paddle with the wall, indicating that the field border has been reached and enables the player to perceive the distance between both field borders. Feedback should also be given if the ball leaves the field, i.e. crossing one of the baselines and one player loses the game.

The only important physical activity the player needs to perform while gaming is to move the paddle along the baseline. Depending on the game layout, the paddle can be moved either from top to bottom, from left to right, or from rear to front. The design of the input interface should allow a continuous movement of the paddle to hold onto the idea of the game. In addition this makes it easier to keep track of the paddle's position.

3.4. Fairness

The social aspect is one of our cornerstones of our work: The game design allows different user groups to play against each other. Two players can choose different presentation and interaction techniques to play the game, meeting best their needs and preferences. Due to different interaction devices and the perception through different modalities it is not always possible to present the information in the same granularity level. This may result in different preconditions for the two players and to an advantage for one player. The game would become boring and frustrating. To overcome this inequity and to increase the fairness the game needs adjustable handicaps (following the idea of the golf system) to reduce the advantages of one player or to increase the advantages for the other player. Parameters for adjusting handicaps can be derived from above requirements, e.g., paddle size, paddle friction, ball speed, etc.

At first glance, PONG seems to be a very simple game. With its few game elements and rules the game is very easy to explain even if the player is not able to see. It turns out that when analysing it from the perspective of human-computer interaction, many parameters have impact on the game, its presentations and interactions. In this section, these parameters are examined, in order to provide useful information for the development of new interaction techniques.

4. Interaction Design

Interaction design defines the behaviour of interactive products. It deals with the communication between human and computer and determines the way information is exchanged. The previous section provides useful knowledge about what information needs to be exchanged for AuditoryPong. This section discusses potential interaction techniques and approaches how the information can be exchanged, such that blind and visually impaired people are able to participate in the game.

From the user's point of view, exchanging information can be categorized into output and input. Output stands for the machine's information presentation, while input means the user's ability to manipulate the state of the system. Designing input and output are parallelized tasks, because they are not independent from each other. For example, depending on the way information is presented, different interaction techniques can be applied, while others are not suitable.

In the following, we provide an overview about different interaction techniques, that we have developed in order to play AuditoryPong. We start with the output design, particularly the auditory output, as this leads to further requirements for the visual output and the input design.

4.1. Output Design

To enable users to play the game non-visually, AuditoryPong is played within a virtual sound room. In this room, virtual sound objects can be placed, representing the game elements and events identified in the previous section.

According to the requirements the ball must be presented continuously to the user. Thus, the ball is linked with a continuous sound. When the ball moves, the according sound object moves in the same direction with the same speed, representing the ball's location. Since a moving ball in the real world has no unique sound, we cannot use a typical "ball-movement-sound", which can easily be identified by the user right away. A single continuously played note would be very annoying. Thus, we use a pleasant melody that is continuously looped as auditory representative. This melody contains a wide band of frequency to ease spatial localization of the ball. The representation of the ball is the most complicated part of sound design for this game. It is the only artefact, which is heard constantly. At every moment the used tones should enable the user to localize the position of the sound in relation to the sound environment surrounding him. As we use the volume to mediate the distance between the user (the paddle) and the ball, the used sound shouldn't have any volume peaks or breaks.

Collisions of the ball with the walls and collisions of the paddles with the walls are presented by short sound effects to inform the player about the respective event. These sound effects are placed at the position where the collision took place to convey the position of the event. In order to help the user to distinguish between different events, each collision is associated with an individual sound. The sounds represent the attribute of the colliding materials. As the ball represents a flexible structure and the wall a very robust structure, the sound should represent, that the ball does not slide on the wall when colliding, but suddenly bounces back with the same angle it hits the wall. So a short hard tone should result in a realistic impression. In contrast to the ball, we can use realistic sounds to mediate collisions, determined by the materials that are colliding. To minimize the number of concurrently played sounds we decided to not represent all information in the auditory modality. Static elements like the walls should be perceived over the haptic modality. So the user has to learn the combination of information from the haptic and auditory modality. They must work together for a realistic game scenario.

In the original visual PONG game, the game is presented by a view on top of the field (bird's eye view). Due to humans' auditory perception, AuditoryPong requires a slightly different presentation of the game field. The auditory resolution is very low in vertical direction (it is hard to accurately locate sounds which are above or below our ears). Therefore, it is not recommended to use a bird's eye view for the auditory presentation, since then the ball and the paddle need to be located on vertical direction. For this reason AuditoryPong uses the perspective 3D view.

By placing a virtual listener within the sound room, the directions and distances of the sound sources regarding the listener's position and orientation can be perceived by the user. The virtual listener is either located centred and in front of the baseline, as shown in Figure 4 on the left, or located centred of the respective paddle, as shown in Figure 4 on the right. From the respective position the player listens to the ball and to any collisions. If the ball approaches to the player's baseline, the ball or more precisely the sound of the ball becomes louder. Hereby he is able to identify the distance of the ball from his position.

Furthermore the user is able to perceive the direction of the sound source. With the information of direction and distance, the user is able to appraise the location of the ball. By observing the ball’s movement the player can determine the ball’s speed and is then able control the paddle accordingly.

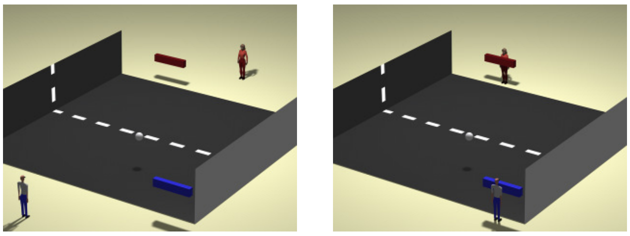

Figure 4: Virtual listener stands centred in front of the field (left) and listener is moved along with the paddle (right)

For the sound design it is important to know, that evaluations showed humans are able to distinguish between about five different positions horizontally (cf. [6]). However, these evaluations took place with static positioned sound sources. Playing PONG the user perceives the additional information through the “history” of the ball’s position. So the user is able to anticipate the next position of the ball. This makes the sound design much easier.

The user has to “calibrate” to get an idea about the velocity of the ball and how fast she has to move the paddle in the right directions. This is a normal process since current soundcards use averaged head related transfer functions (HRTF) to present the virtual sound rooms. These algorithms can not reflect the player’s individual hearing characteristics. When using headphones for the game the user has to adapt to the used (HRTF) that renders the sound environment. So the longer the user plays the game the better he learns this transfer function and will perform better in the game.

As shown in Figure 4, the user perceives the ball from back to front and left to right or vice versa. From this it follows that the user moves the paddle horizontally to hit the ball. Additionally to the auditory output, we equipped AuditoryPong with a visual display for sighted people. In case users like to use both presentation techniques, the visual output should comply with the auditory output, in the sense that the paddle should be moved in the same direction, in order to avoid discrepancies between different output and input techniques. The layout of the visual game field of AuditoryPong is therefore vertically, i.e. the baseline will be on the bottom of the screen.

4.2. Input Design

With the original PONG console the players use adjusting knobs to move the paddles. With these knobs the requirements described above are only fulfilled if the game is played with a visual output. The auditory output alone cannot adequately fulfil all requirements since, for example, the field’s extend is not presented explicitly. Therefore, we developed or adapted different input devices to use them for AuditoryPong. We particularly address if and how the respective input device helps to fulfil the following requirements:

- Present the paddles size and location
- Convey an impression of the field’s extend
- Move the paddle continuously

As these input devices are not used in everyday live in combination with the sound output, the user has to learn the usage of the input devices with the sound feedback.

We started with the traditional computer input devices mouse and keyboard that provide no information about the paddle’s size and location. We connected the user’s physical sensation with the paddle using a digitizer tablet and a physical slider. Finally, leaving typical computer peripherals as input devices to play the game, we allowed the players to steer the game with their own body movement using head tracking and body tracking technology. In the following we describe these input devices and their respective strengths and weaknesses in more detail.

4.2.1. Mouse and Keyboard

Mice as well as keyboards are the most common computer input devices. Both devices can be used to move AuditoryPong's paddles. If the mouse is moved to the left or the left arrow key is pressed, the paddle moves to the left. Moving the mouse to the right or pressing the right arrow accordingly results in a movement to the opposite direction.

Since mouse and keyboard are relative input devices and do not use absolute coordinates, the user cannot move the paddle to a specific position. In addition, the player receives no information about the paddle’s position and size. The player only gets a rough idea of the field’s extends due to the sound which is played if the paddle hits a wall. Furthermore, the keyboard does not allow continuous movement of the paddle. In general the mouse is an inadequate input device for blind and visually impaired people as it is very hard to use without the hands-eyes coordination. However, in connection with visual output, which provides a visual frame of reference, mouse and keyboard can be used for sighted user.

4.2.2. Joystick

Analogue and digital joysticks are common input devices for many computer games. For AuditoryPong we use an analogue joystick, shown in Figure 5, which provides precise information about how far the stick is moved in each direction. If the joystick is in its centred position the paddle is centred as well. If the stick is moved along the X axis the paddle accordingly moves in the same direction. The paddle hits the wall if the joystick is moved to one of its border positions.

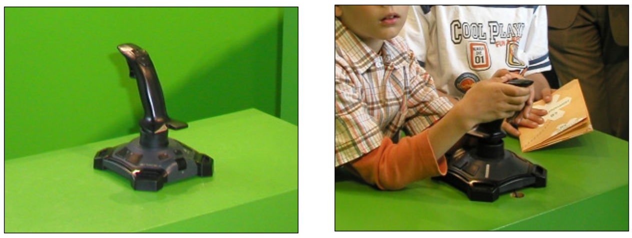

Figure 5: Joystick provides continuous movement and absolute positioning of the paddle

The joystick is used as an absolute input device. The frame of reference is defined by the joystick’s two extreme positions. Thus, the player can move the paddle to specific positions and receives information about the paddles position. However, the frame of references can not be perceived continuously and thus not very precisely and intuitively. In addition, no information about the paddle’s size is conveyed. The player is assisted in getting an idea of the field’s extents due to the joystick’s physical resistance if the paddle hits a wall and the stick its extreme position. The joystick allows continuous movement of the paddle.

4.2.3. Digitizer Tablet and Slider

To enable the player to continuously feel the frame of reference we connected a digitizer tablet (Figure 6). The game's baseline is mapped on the X axis of the digitizer tablet. Thus, the game's left wall is at the tablet's left side, and the right wall is on the right side. The tablet itself is equipped with a physical border and tactile markers, which the player can feel with his or her hands. Using the tablet's stylus, the paddle can be moved by touching and moving the stylus on the tablet.

Figure 6 Digitizer tablet provides a frame of reference and absolute positioning

Markers on the tablet, which symbolise the game's walls, clearly define and convey a frame of reference which the user can perceive continuously. Thus, the player can move the paddle and receive the paddles position precisely. The player gets a clear idea of the field's extents and the stylus allows continuous movement of the paddle. However, the stylus does not provide any information about the paddle's size.

To provide the player with even more comprehensive feedback and enable him or her to identify the paddle's size we incorporated the concept of tangible user interfaces (TUI) [7]. In the context of TUIs the slider's handle is a physical artefact that is connected with digital presentation of the paddle. According to Ghazali and Dix [8] the behaviour and appearance of the paddle's physical artefact should correspond with the behaviour and appearance of the virtual paddle. Thus, we build the slider so that the physical handle has the same size as the virtual paddle. Our sliders are presented in Figure 7.

Figure 7: Slider mediate a frame of reference and the size of the paddle

4.2.4. Head Rotation

If the player uses headphones, the sound room rotates with the head, which gives an unrealistic impression of the perceived acoustic environment. In the real world a sound source in the front is equally loud on both ears. After turning the head to the right the sound can be heard stronger on the left side than on the right side. Thus, in the real world we are enabled to perceive the direction of sound sources very accurate. To achieve increased user-immersion we mimic the real world's acoustic behaviour. The orientation of the virtual listener inside the sound room is adjusted according to the orientation of the user's head. This orientation is tracked by a Flock of Birds Headtracker from Ascension Technology. The Headtracker's small sensor is attached to the headphones as shown in Figure 8. By adjusting the acoustic output according to the the head's orientation the user gets a more realistic sound impression. Thus, the user can locate the ball and other sounds more accurate.

To enforce the user to experience the improved acoustic presentation she can control the paddle by rotating the head. The paddle moves according to the user's line of sight. Moving the head to the left or to the right steers the paddle to the left or to the right on the vertical game board. By virtually "looking" at the ball the ball's sound is equally loud on both ears and the paddle is in the right position to hit the ball. Thus, it is easy to hit the ball by simply facing in the right direction.

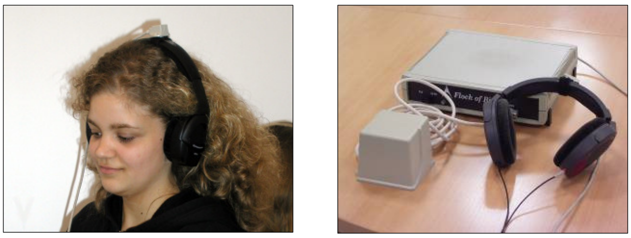

Figure 8 Moving the paddle by rotating the head

4.2.5. Body Movement

To relieve the player from sitting in front of the desk we turn PONG into a pervasive game and release the game from the computer chair. We connect the virtual game board with a real room. The physical walls of the real room represent the two walls of the game. The user body represents the paddle in physical game board. By physically moving his or her body between the two walls the user moves the virtual paddle. In addition, the position of the virtual listener within the sound room is moved according to the user's real position.

Figure 9 Pervasive interaction with face tracking

To redeem the user from any cables we use wireless headphones and determine the user's position using face-tracking technology as shown in Figure 9. The user moves in front of a Web cam that captures the scene and detects the player's face. While the user moves to the left or to the right, the camera tracks the face in real time. As there is no visual display the user relies only on the physical movement in the room and the acoustic feedback.

5. Game Demonstrator

We have developed an AuditoryPong demonstrator and tested the interaction techniques at several public events. In the following sections we describe the design and implementation of AuditoryPong and summarize our demonstration experiences.

5.1. Design and Implementation

AuditoryPong has been designed as a multiplayer game which can be played over the Internet. We implemented pong using a client/server architecture. The server processes the game logic, for example calculating the position of the ball. The thin client is responsible for the user interface, i.e. presenting the game elements and game events, and processing the user inputs. Client and server can be run on the same machine to also allow local gaming with two players. The client architecture is illustrated in Figure 10.

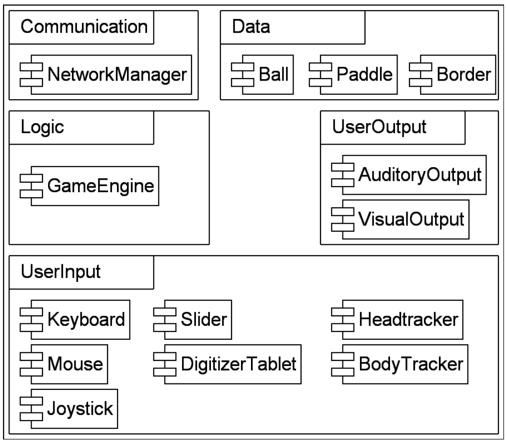

Figure 10: AuditoryPong's architecture

The architecture consists of five main components: Communication, Logic, Data, UserInput, and UserOutput. The communication component encapsulates the network communication with the server (sending and receiving game events). The data component represents the models of the game elements, stores and manages their properties, and provides functions to manipulate and access their states. The user interface is realized by the UserInput and UserOutput components. Status changes received from the game logic are processed and outputs for the currently active output device(s) are generated by the UserOutput classes. The UserInput classes receive any events from the input devices and calculate new states of the game elements. The logic component initializes and manages all other client components, provides interfaces and forwards messages between the data component, the network, and the user interface.

Besides the more essential components, our demonstrator provides accessible dialogues to configure the game. Configurations can be stored in profiles that include the input and output device, the network setup, and fairness parameters like paddle size, paddle friction, and speed of the ball. Furthermore the player can choose between different sound and graphics themes.

AuditoryPong is implemented in C++. For the non-speech 3D sound we used a sound framework for auditory displays that we have developed earlier [9]. The sound framework can be used with various sound libraries and APIs like EAX, DirectSound, A3D, FMOD and OpenAL. For the face detection and tracking we used algorithms provided by the Open Source Computer Vision Library (OpenCV) [10]. Other devices are connected via standard C++ libraries.

5.2. Demonstration Experiences

AuditoryPong has been demonstrated on several public events. The most prominent event was the Ideas Park organized by ThyssenKrupp [11] where about 3000 people dabbled in the game. Two players – mainly between 8 and 16 years old – competed at a time. One player played with a visual screen and the joystick as input device, the opponent played without visual feedback within a box using the slider to control the paddle and speakers for the sound output. The player with the visual feedback was handicapped by higher ball speed, paddle friction and a smaller paddle. After a really short familiarization time (about one minute) both players were mostly able to play the game against each other over a longer period of time. The interfaces came out as very easy to learn and extremely robust. Most players quoted to have fun with the game and were surprised that blind players were able to keep up with sighted users. The fairness functions helped to balance the different handicaps of both players.

There have been several regional events with between 10 and 300 visitors, to whom we have demonstrated AuditoryPong along with its different interfaces: Long Night of Computer Science [12], Girls' Day [13] (both supported by the German Federal Ministry of Education and Research), and dorkbot [14]. The experiences at those events provided us with further feedback about the implemented interaction techniques. Most of the players' statements can be compared with those from the Ideas Parks. The computer vision based body movement input technique turned out as not as robust as the slider or digitizer tablet due to unstable lightning conditions. However, playing a computer game without a monitor or the need to use an extra device to control the paddle provided the players with new interaction experiences.

Within the project ENABLED [15] AuditoryPong is used as a training application for blind and visually impaired people. In ENABLED applications are developed, which mediate spatial information non-visually through 3D non-speech sound. AuditoryPong serves as practice for those applications and to get familiar with the new interface through play. Interviews showed that blind and visually impaired people were able to play the game easily and that they learned the spatial relations between the different game elements without difficulties. They stated that AuditoryPong is a useful introduction to auditory displays and trains in localising synthesised sound objects.

6. Conclusion and Future Work

In this paper, we presented AuditoryPong, an advancement of the original computer game PONG, which can be played with or without a visual screen by both blind and sighted players together. We analyzed the different game elements, game events, and control requirements of the original PONG, in order to determine the necessary information and input mechanisms that need to be provided to the user for playing. Transforming the visual game into a non-visual playground, we designed a new user interface and new interaction methods: Core of the interface is the spatial non-speech audio component which presents the game elements and their spatial relations. We developed and integrated different input techniques, which enable the user to control the game. Some of these input techniques make use of haptic devices, which also present information about the game state and thus support the auditory output. Computer vision based face detection allows controlling the game by moving the own body, putting the player in a fully immersive environment. The interaction methods were evaluated through several public events.

With AuditoryPong we showed that visually oriented applications, such as games, can be made accessible for blind and visually impaired people through non-visual interfaces. From AuditoryPong we aim to learn about multimodal interaction techniques and transfer our experiences to other application areas beside games. Experimenting with different modalities and devices we develop non-visual interaction paradigms that come naturally in different stationary or mobile situation. In the future we will further improve the existing interaction techniques and investigate new non-visual interaction methods. In particular the combination of auditory displays and haptic and gesture interfaces looks promising for perceiving and exploring spatial information.

Acknowledgments

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